Experimental Verification of Range-Dependent Inversion: Shallow Water Experiment 2006

Subramaniam D. Rajan
Scientific Solutions, Inc., 99 Perimeter Road, Nashua, NH 03063
phone: (603) 880-3784   fax: (603) 598-1803   email: srajan@scisol.com

LONG-TERM GOALS

Develop methods for rapid assessment of sediment properties relevant for acoustic propagation in a range-dependent shallow water environmnt

OBJECTIVES

Modal dispersion data i.e. mode arrival time as a function of frequency have been used in inversion schemes that estimate sediment properties in a range-independent environment. This method has now been extended to include range-dependent environment. Simulation studies show that range-dependent sediment properties can be extracted if modal dispersion data are obtained for multiple source/receiver locations. It is proposed to collect suitable data during the Shallow Water 2006 experiment to verify the feasibility of estimating the range dependent sediment properties.

The inversion method based on mode dispersion data is one of the approaches that can be used to estimate the sediment characteristics. The other method employs the modal eigenvalues as data. The Shallow Water 2006 experiment was designed so as to collect co-located data sets so as to perform inversions using both these techniques. The overlapping data sets will provide a direct means of comparison and validation of the two inversion approaches. It is proposed to make measurements on a common moored receive system for a towed cw point source (J15-3)/towed air gun source. In addition to the acoustic measurements, supporting environmental data will be collected using the CTD chain. The CTD chain will provide a detailed picture of the spatial sound speed structure in the water column during the acoustic transmissions.

APPROACH

In shallow water, the acoustic field can be represented as a sum of contributions from a set of propagating modes. It is well known that modal dispersion data contain information about the characteristics of the shallow water wave guide including the acoustic characteristics of the sediment. Inversion scheme that use the modal dispersion data for estimating sediment acoustic properties in a range independent environment has been described in the literature [1]. This approach has been modified to determine the sediment properties in a range-dependent environment as outlined below.

Using perturbation analysis, the perturbation dt_n in the arrival time of mode n at the receiver due to perturbation in the compressional wave speed is given by

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14. ABSTRACT
Modal dispersion data i.e. mode arrival time as a function of frequency have been used in inversion schemes that estimate sediment properties in a range-independent environment. This method has now been extended to include range-dependent environment. Simulation studies show that range-dependent sediment properties can be extracted if modal dispersion data are obtained for multiple source/receiver locations. It is proposed to collect suitable data during the Shallow Water 2006 experiment to verify the feasibility of estimating the range dependent sediment properties.

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$$dt_n = \frac{\partial}{\partial \omega} \int_0^r \int_0^\infty \frac{1}{k_n(s,\omega)} \frac{\omega^2 \Delta c(s,z)}{c_b^3(s,z)\rho_b(s,z)} \left| \phi_n(s,z,\omega) \right|^2 dsdz \qquad (1)$$

where ω is the frequency of the acoustic source, $k_n(s,\omega)$ is the eigenvalue of the nth mode, $c_b(s,z)$ is the unperturbed compressional wave speed of the sediment, $\rho_b(s,z)$ is the density of the sediment, $\phi_n(s,z,\omega)$ is the mode function of the nth mode, r is the range to the receiver, $\Delta c(s,z)$ is the perturbation to the compressional wave speed and s and z represent the range and depth locations. The double integral can be changed into a double sum given below.

$$dt_n = \sum_{p=1}^P \sum_{q=1}^Q A(s_p, z_q) \Delta c(s_p, z_q) \qquad (2)$$

This double sum can be reduced to a matrix equation and the equation solved to determine the quantity $\Delta c(s_p, z_q), p = 1, \cdots, P, q = 1, \cdots, Q.$ In converting to the integral to a matrix equation we assumed the region is discretized in both range and depth. The argument s_p refers to the pth step in range and z_q refers to the qth step in depth.

WORK COMPLETED

The method outlined above was tested with simulated data. The simulation study indicates that it is necessary to obtain data with multiple source/receiver combination in order to extract the range dependent property of the sediments. The ability to determine the modal arrival time with sufficient accuracy from the broad band data was also investigated. Analysis using Short Time Fourier Transform (STFT) and Continuous Wavelet Transform (CWT) were studied. In order to improve the accuracy of the mode arrival time estimates, time-frequency analysis using a modified form of short time Fourier transform that takes into account the dispersive nature of the propagation was studied. The proposed modification to STFT is the dispersion based STFT where the tiling in the time-frequency plane is made dependent on the dispersive character of the propagating waves[2]. The method is based on chirplet transform[3] which allows a generalized time-frequency tiling. This leads to a more accurate estimation of the modal arrival time.

In a field experiment, it is not always possible to synchronize the transmission of the signal by the source with the data acquisition system. Under these circumstances, it is not possible to determine the absolute arrival time of the modes. What is possible to determine is the arrival in terms of an arbitrary zero time. In these cases, the algorithm developed above will have to be modified to include the difference in arrival time between modes. Simulations to test this method were also performed and it was shown that the range-dependent sediment properties can be determined.

In order to design the Shallow Water 2006 experiment, the following modeling effort was undertaken.

1. Determine the source parameters for the experiment

2. Determine the experimental configuration

3. Develop experimental plan

During August 2006, data suitable for evaluating the proposed inversion schemes were collected as part of the Shallow Water Experiment 2006.

RESULTS

The shallow water experiment was conducted during August-September of 2006. Details of the various arrays other in water assets that were deployed during the experiment are available at http://sealion.whoi.edu/sw06-bin/logistics. During the execution of the MIME experiment a number of changes had to be made to the proposed experimental scenario. Firstly due to time and other considerations, it was not possible to collect data with the source moving along a circular track of radius of 10 km with the vertical array deployed by WHOI as its center. Instead the data were collected with source placed at locations along two circular arcs as shown in Figure 1. This will reduce the region over which it may be possible to obtain the geoacoustic parameter from the data.

Figure 1 also shows the location of the vertical array of receivers. The vertical array consisted of 16 elements. In addition to the vertical array, a horizontal array was also deployed at the location of the vertical array. One end of the horizontal array coincided with the location of the vertical array and the farther end of the array was approximately 450 m away. Survey of the location of the horizontal array indicated that it was reasonably straight during its deployment. In addition to the vertical array there were single hydrophone deployed in the vicinity of the vertical array as shown in Figure 1.

Initially it was proposed to use an air gun as the broad band source. However due environmental impact considerations the use of air gun as a source was disallowed. So a broad band signal (Linear frequency modulated signal) was transmitted using the J15 source. The bandwidth of the signal was 200 Hz i.e. the linear sweep was from 50 Hz to 250 Hz. The duration of the pulse was 0.5 sec. At each location multiple pings were transmitted so as to enable some averaging to be done to improve the SNR. The total transmission time at each location was approximately 12 minutes. This gave about 240 pings at each location.

During the course of the experiment, the sound speed structure in the water column was obtained using a CTD chain. The chain was towed by the ship that towed the source. The sound speed structure at the location of the source was measured. The chain has 21 sensors distributed along the length of the chain. The sensors of the chain make measurements of the temperature, conductivity and pressure every 2 seconds. The sound speed profile is computed from the values of the temperature, and conductivity at each sensor as a function of time. The evolution of the sound speed is shown in the upper panel of Figure 2. The lower panel shows all the sound speed profiles. It is seen that the data has many outliers and these have to be identified and dealt with. It is also seen that the sound speed is profile is stable over the time period.
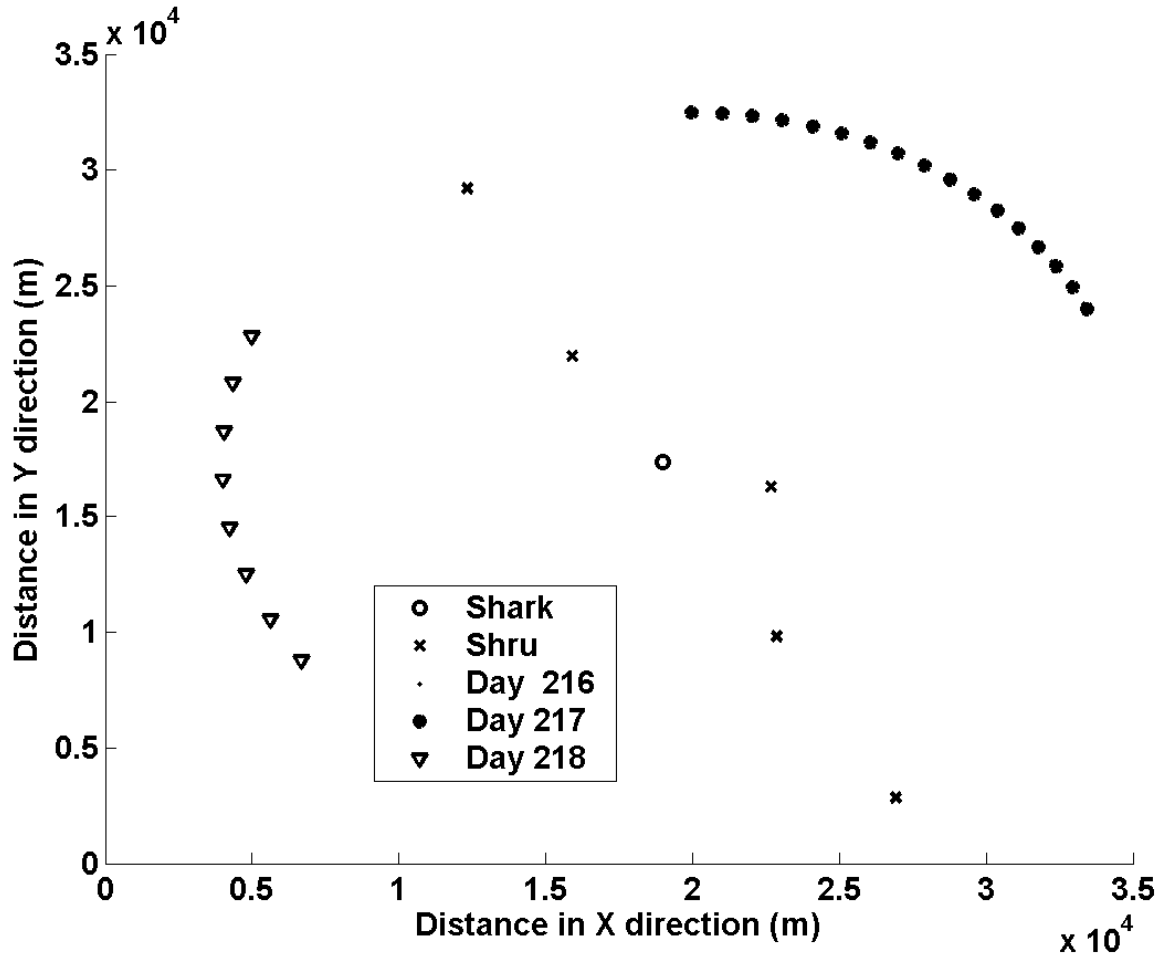
Figure 1. Location of broad band shots and receiver arrays.
The figure shows the location of the array Shark (an array of 48 elements
of which 16 elements form the vertical array and the remaining 32 are
the horizontal array) and single hydrophones Shru 49 to Shru 53.

The spectrogram of 30 seconds (10 pings) of data is shown in the left panel of Figure 3. The LFM sweep is clearly seen in the figure. The right panel shows the raw signal of one of the pings and its time-frequency representation. Two mode arrivals are seen in the data. Analysis of data to extract the mode arrival times for different source/receiver geometries are in progress. This will be used to determine the range-dependent sediment properties.

IMPACT/APPLICATIONS

The data collected during this experiment will enable validation of the proposed method for estimating range-dependent sediment compressional wave speed from modal dispersion data. Data collected using a narrow band source will be used to estimate the sediment compressional wave speed from modal eigenvalues. A direct comparison between the two methods can therefore be done as the data

will be collected at the same location. Extensive environmental measurements taken during the experiment will help in assessing the impact of variability in water column characteristics.
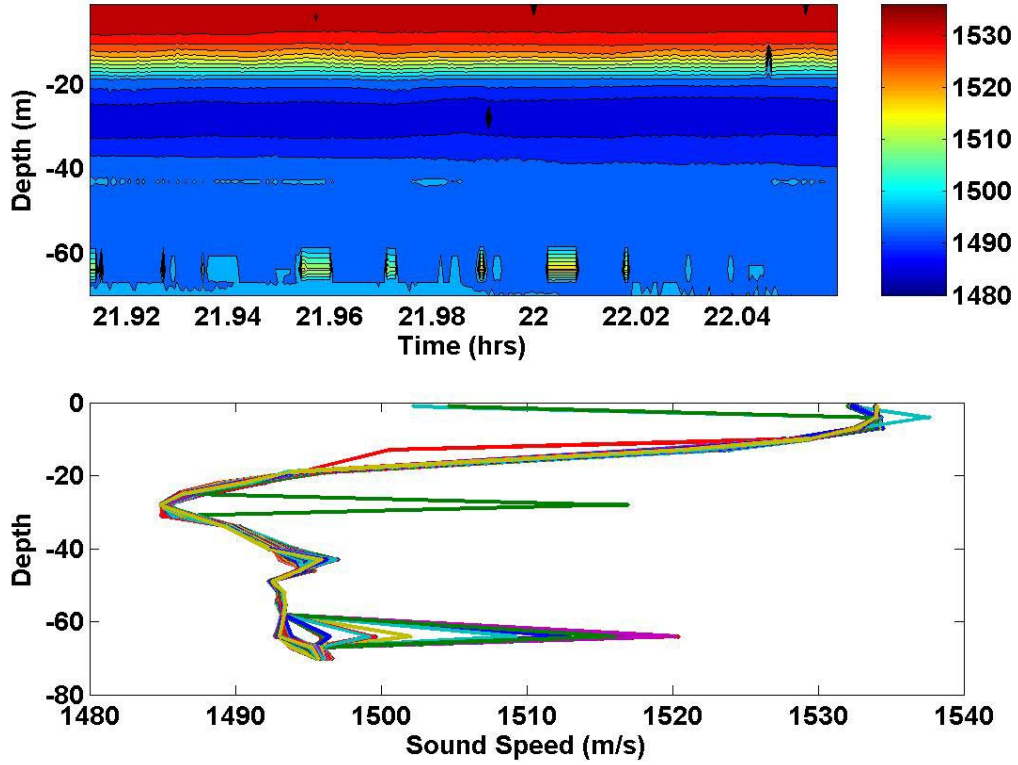

Figure 2. Top panel shows the evolution of the sound speed profile with time.
The lower panel shows all the sound speed profiles. There are outliers in the data and
these have to be identified and eliminated in order to obtain an average sound speed profile.
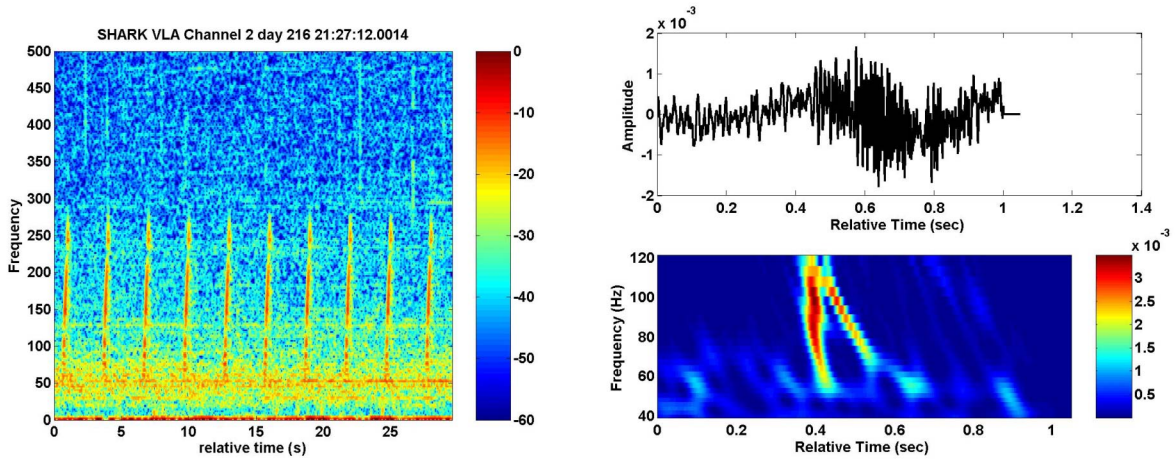

Figure 3. Left panel shows the spectrogram of 10 pings.
The right panel shows the raw signal of one ping and its time-frequency representation.

RELATED PROJECTS

As part of Shallow Water 2006 experiment a modal mapping experiment will also be conducted. This experiment also envisages estimation of sediment characteristics from modal eigenvalues. Results from this experiment will help in validating the results of broad band experiment outlined in earlier sections.

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